Performance analysis of waste to best solar water heater

Dharmesh.J. Chavda[1], Sanjeev.D. Suryawanshi[2]

[1] B Tech Mechanical Engineering, S.S.V.P.S. B.S.D COE, Dhule 424001 (India)

[2] Department of Mechanical Engineering, S.S.V.P.S. B.S.D COE, Dhule 424001 (India)

Abstract

Water heating is an essential aspect in the industrial and domestic purposes. Various methods have been adapted for heating water. Fossil fuels and electricity are widely used for water heating which consumes more high-grade energy and causes pollution. Due to increase in population, consumption of fossil fuels has drastically increased. These precious conventional resources depleting with time. Here the non-conventional resources come in to the picture. Solar water heating is a promising solution for water heating in the both domestic and commercial applications. But the solar water heaters are quite expensive and cannot be afforded by common peoples. In search for affordable solar water heating solution waste water bottles can be used as a glazing, since plastic waste management is serious issue throughout the world. Solar collector is developed and tested using PVC pipes as an absorber and transparent waste bottles as a glazing. Additional removable glazing cover of polyethylene improves performance in acute winter. Bottom part of transparent bottles covered with reflective foil to augment collector's performance. It generates hot water up to the temperature 66^0C, with good structural rigidity of the collector.

Keywords: *PVC pipes, waste bottles as glazing, glazing cover, headers, reflective foil*

1. Introduction

Water heating is the crucial part in the industrial and domestic applications. Fossil fuels are widely used in the water heating application. About 8% of all end-use natural gas is used to heat water in commercial and residential buildings [1]. Major energy used for water heating include natural gas, electricity, oil, and liquefied petroleum gas (LPG) [1]. Despite the popularity of wood as an energy source for water heating, its use might have harmful effects on health when rudimentary stoves are used as the burning means; such devices allow the smoke to pollute the household air with ashes [2]. Therefore, use of solar energy for water heating is the promising solution to reduce the use of fossil fuels. The ETC type solar water heater is quite expensive and cannot be afforded by many peoples. Many researchers are working to discover affordable solar water heating solution. A solar water heater prototype was constructed using polyethylene terephthalate bottles to determine its feasibility as a component of the average household in rural areas in Guatemala [3]. A solar water heater design made from plastic bottles of Pepsi or Miranda with plastic pipes run up the center of each row of bottles. These bottles act as glazing, and also hold reflectors made from beverage cartons [4].

Nonbiodegradability of plastics is attributed towards causing waste management problems and choking of the drains in urban cities [5]. Some types of plastic waste like multi layered laminates; EPS, etc. are not easily recyclable by conventional process [5]. So, using of waste bottles can be beneficial for the environment and reduces the cost of the solar water heater. The Indian patent is granted entitled "Solar collector using plastic glazing", Patent number 455451, dated 27/09/2023. Most of the evacuated tubes are imported from China [7], it is decided to have indigenous development of solar water heating system that gives some of the advantages of flat plate collectors (FPC) and some of the ETC. In FPC forced circulation, draining of deposited salts is possible and for ETC no insulation is required for collector.

Mostly water heating from combustion of fossil fuel is the practice in rural areas, the problem is more acute with poor financial background. It is decided to manufacture a cost-effective solar water heater.

Therefore, it is decided to manufacture a setup and to analyze the performance of the collector with PVC pipes as an absorber and the waste bottles as a glazing, with an additional removable glazing that will improve the performance of the solar water heater in acute winter.

Selection and/or peer review under responsibility of Scientific Committee
10.18086/swc.2023.10.01 Available at http://proceedings.ises.org

2. Materials and methods

Present system of waste to best solar water heater consists of,

1. Matt black painted PVC absorber pies
2. Transparent plastic bottles (polyethylene terephthalate)
3. Mild steel supportive frame
4. PVC plumbing accessories
5. Reflective foil
6. Clear silicon sealant
7. Teflon tape

Present setup is environment friendly, indigenous, safe and low cost since the material used is easily available at low cost in India. In today's scenario disposal of waste plastic bottles is a big question for ecological researchers. It's a need of an hour to utilize waste plastic bottles effectively. In conventional FPC solar water heater system the convection losses are more in acute winter compared with present study.

For manufacturing the collector, the bottles are cut from mouth end side and holes are pierced in the base of bottles with predefined dimensions. The bottles after preparation are inserted with interference fit over the absorber pipes. During inserting the bottles over the pipe, the mouth end side should match with base side of next bottle as shown in figure 1. Bottles are inserted from base side over the absorber pipe. This interconnected part of bottle is sealed by some sealant, preferably clear silicon sealant to have air tight connection between two bottles. Clear silicon sealant allows solar radiation to pass through and maintains the aesthetics of collector.

The absorber pipes with bottles are connected with tee at top and bottom to have respective headers of the collector, this will form an array of the pipes which makes the collector. To facilitate effective use of most of solar radiation entering through aperture on the collector, one third arc of outer bottom surface of transparent bottles are covered by reflective foil to reflect solar radiation towards the bottom side of black absorber pipes of the collector.

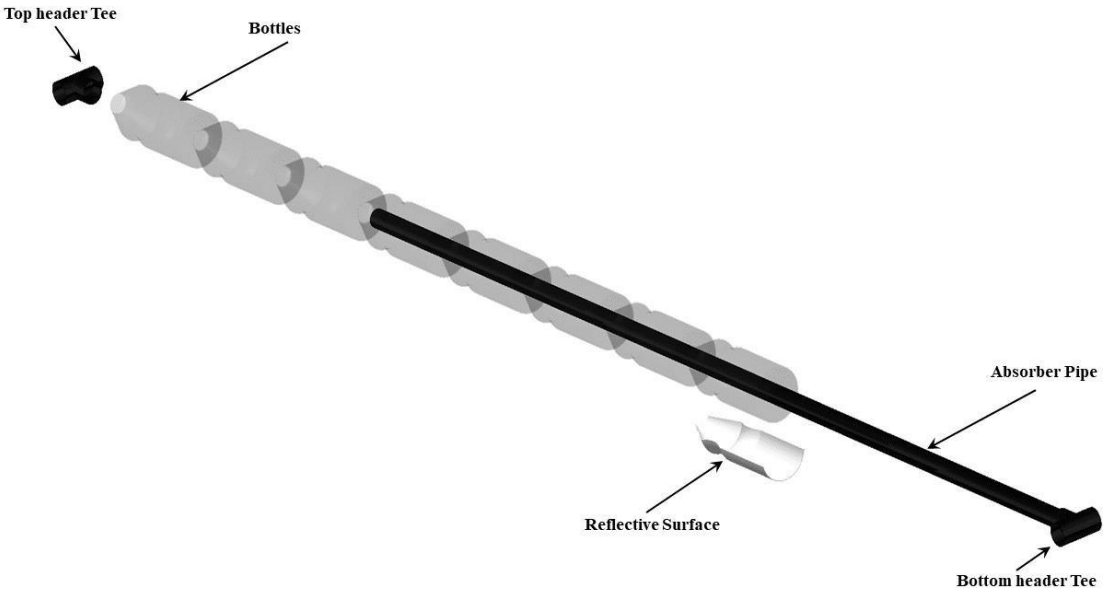

Figure 1: Elements of the collector

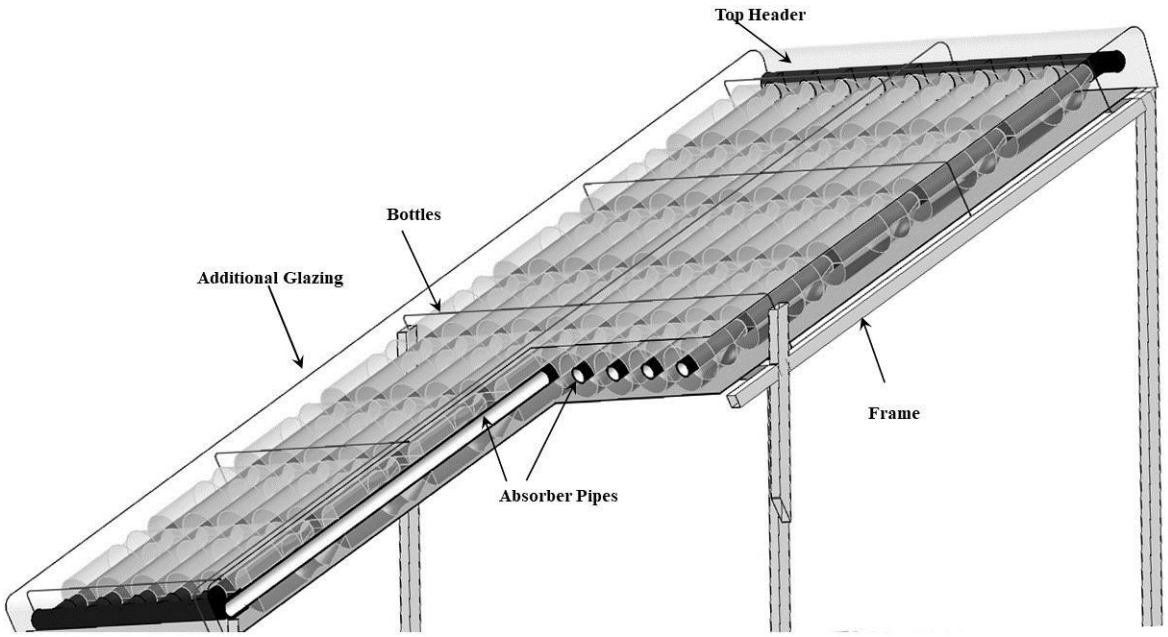

Figure 2: Sectional view of collector, model 1

3. Experimentation

In the present experimental setup, the absorber pipes of collector get heated by absorbing incoming solar radiation, this heats the water, develops a thermosiphon circulation in between the collector and hot water tank. Temperature of the hot water increases until the thermal equilibrium between collector and the surrounding is reached.

The performance of the solar water heater depends on various aspects, one of it is “Dead Volume”, dead volume is the water present in the solar collector apart from the water in the hot water tank. This dead volume directly impacts on the solar water heater performance i.e., if the dead volume is more the time required for heating the water and developing thermos-syphon increases, which reduces efficiency. The performance of the solar water heater system is strong function of this dead volume specifically in monsoon, when *intermittent solar radiations* are available. For lesser dead volume the thermo-syphon circulation is faster, once the water is heated and circulated, it will be stored in hot water tank. Therefore, the main objective of the experimentation is to reduce the time required for the water heating by decreasing the *dead volume*.

It is decided to develop three models for the test setup as follows

1st model is made with array of 32mm diameter pipes as shown in figure 3.

2nd model is made with array of 32mm pipes eccentrically fixed inside 40mm diameter pipes as shown in figure 4.

3rd model is made with array of 40mm pipes eccentrically fixed inside 50mm diameter pipes shown in figure 5.

Eccentrically fixing the pipes as shown in figures 3 to 5 not only improves utilization of incident solar radiation but also decreases dead volume in the collector, intensifies the thermosiphon circulation between the collector and hot water tank. To have eccentric insertion of inner pipe in outer pipe, spacers are sticked on top circumference of inner pipe of proper dimensions at four locations (not shown in figures). Top and bottom ends of inner pipe are sealed with cap and sealant to have air tight connection.

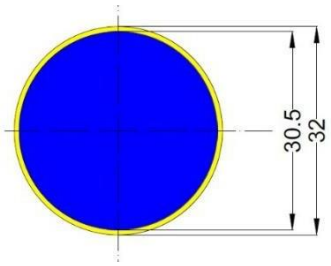

Figure 3: Cross section of pipe of model 1

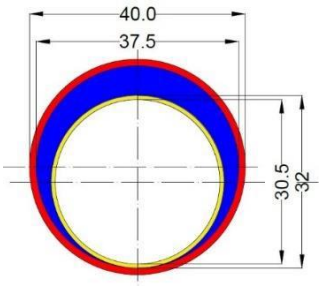

Figure 4: Cross section of pipe of model 2

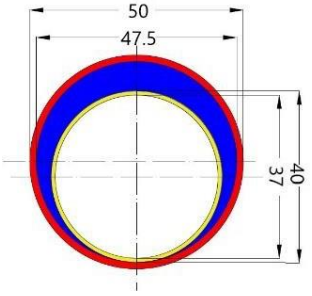

Figure 5: Cross section of pipe of model 3

(Blue shaded part shows the water)

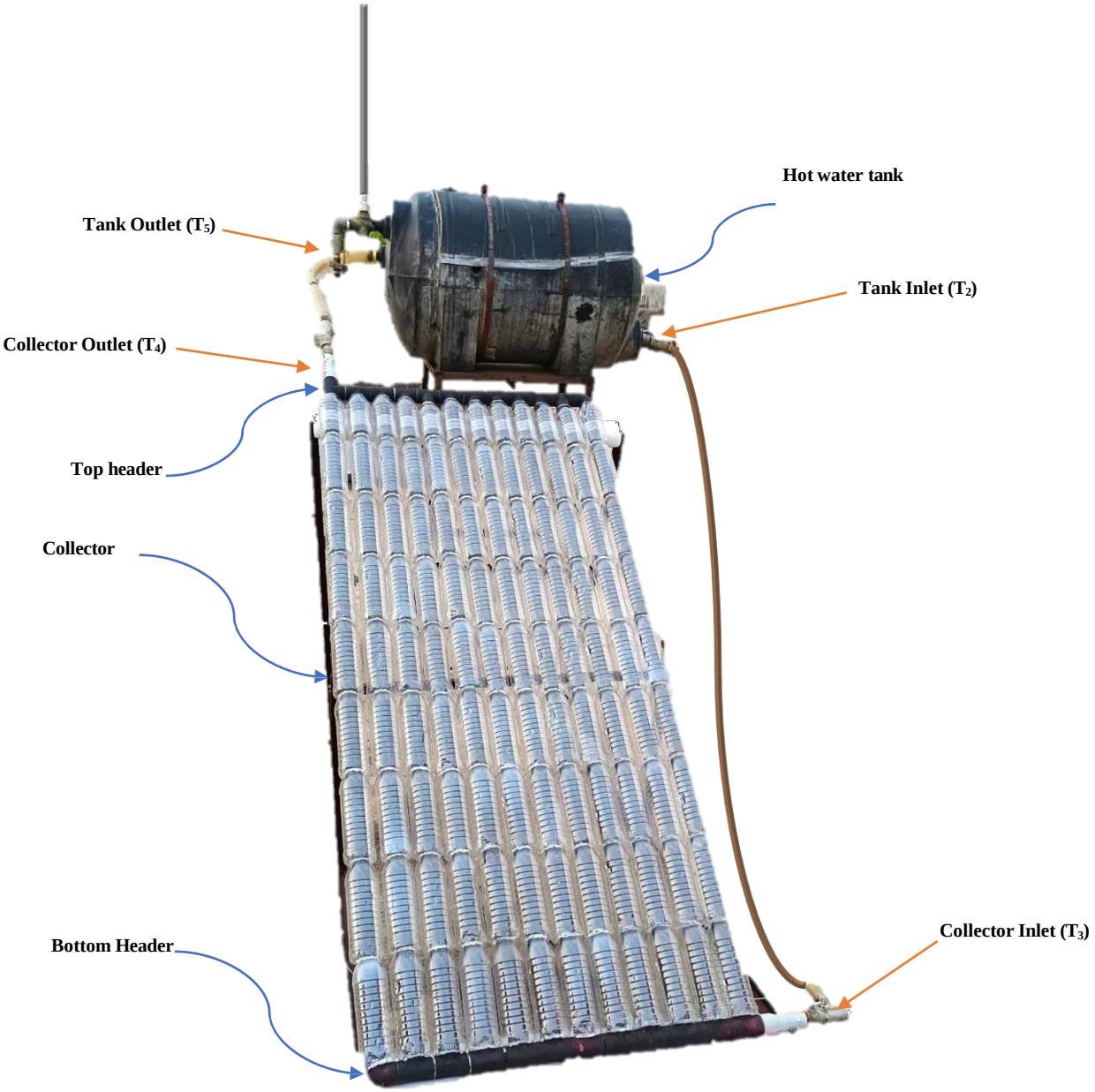

Figure 5: Experimental setup.

4. Results and discussions

In this experiment the test was carried for 2x1m solar collector, the following readings were taken at regular intervals of time of the three models. The observations were taken for three models of present experimentation and compared with ETC collector. All models are of 100-liter capacity.

Tab. 1: Comparison of three Models with ETC

	Model 1	**Model 2**	**Model 3**	**ETC**
Solar Aperture* m^2	0.768	0.96	1.2	0.66
No of pipes/tubes	12	12	12	10
Dead volume liters	13.6	5.5	9.5	19.34
Time taken to reach maximum temperature in hours	6.5	4.5	5.5	5.2
Maximum temperature at collector outlet °C	53	66	58	67

[*Effective aperture which utilizes direct incident solar radiation]

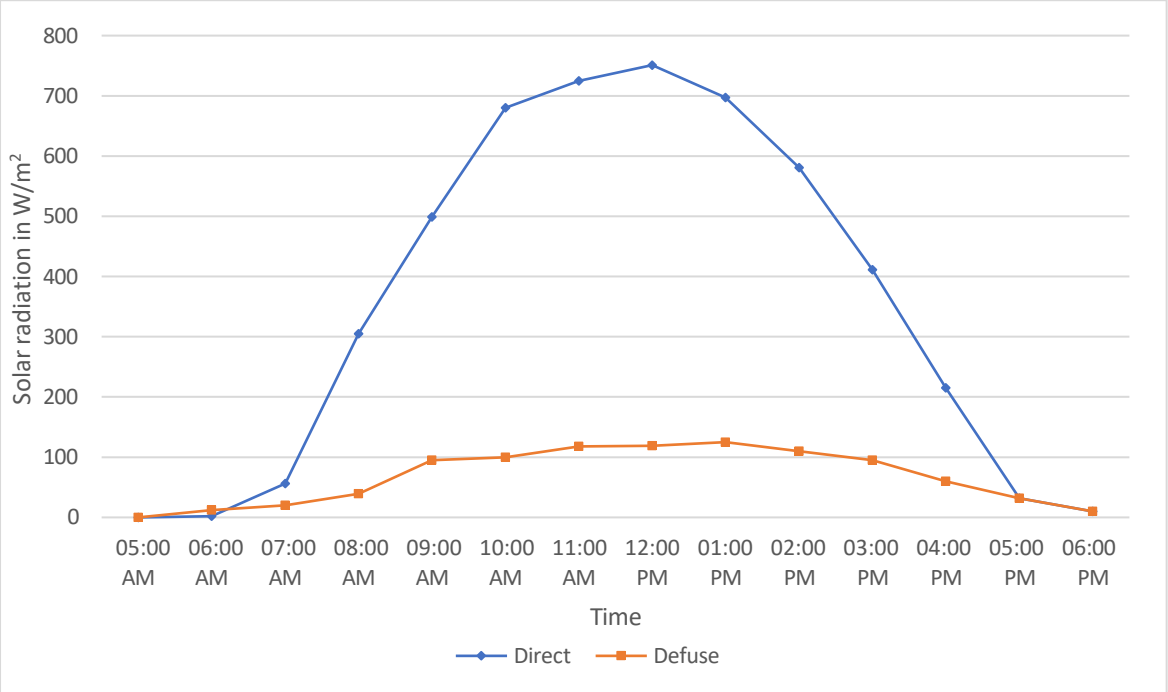

Figure 6: Solar radiation intensity

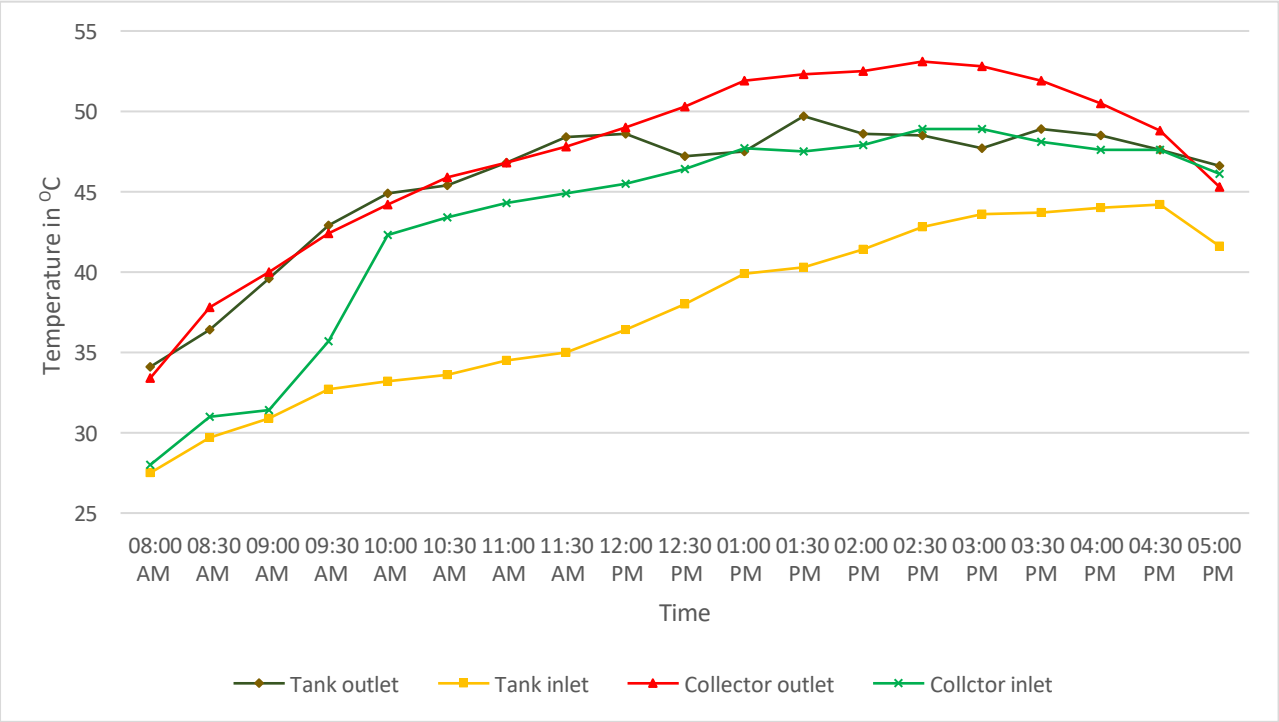

Figure 7: Temperature readings for model 1

4.1. Model 1

Figure 7 shows the performance of model 1 where the collector is constructed with the 32mm pipes. The readings were taken from 8:00 AM with the initial temperature at inlet 26°C. The dead volume in model 1 is 13 liters. Time required for the water to reach maximum temperature is 6.5 hours at 2.30 pm with temperature of 53°C.

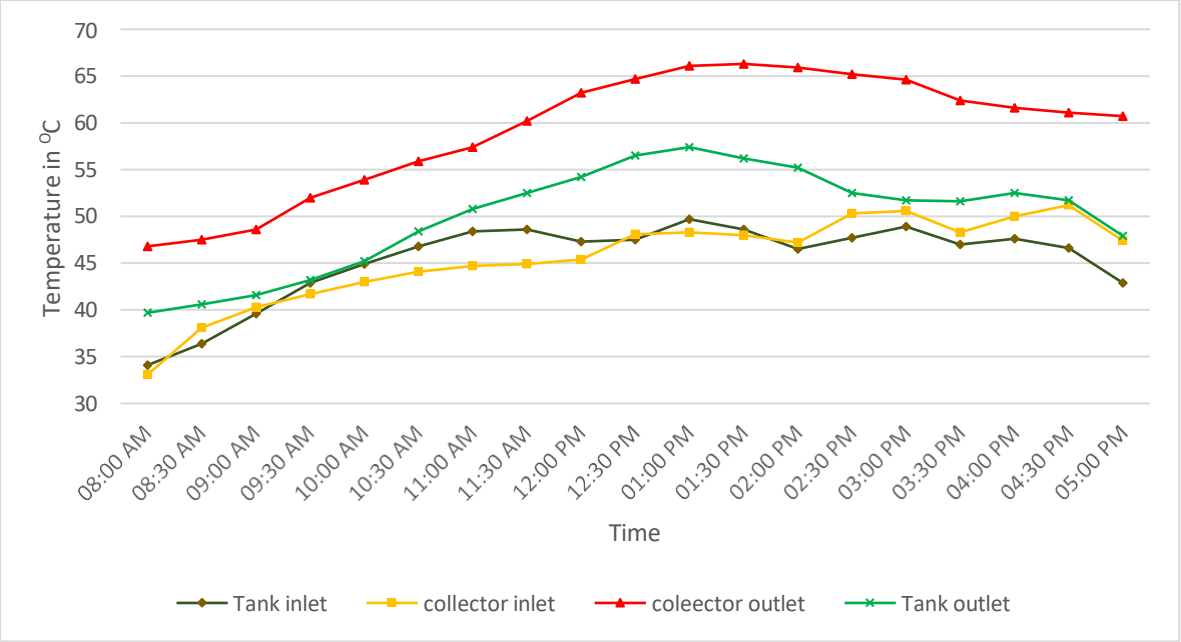

Figure 8: - Temperature readings for Model 2

4.1. Model 2

Figure 8 shows the performance of model 2 where the collector is constructed by 32mm diameter pipes eccentrically fixed inside 40mm diameter pipes. The readings were taken from 8:00 AM with 32°C initial temperature at the inlet. The dead volume in model 2 is 5.5 liters. Time required to reach maximum temperature of 66. 2°C of the water is 4.5 hours this temperature is attained at 1.30 pm. It is observed that due to reduction in dead volume compared with model 1 time required to reach maximum temperature of water outlet from collector is reduced, also the maximum temperature achieved is elevated.

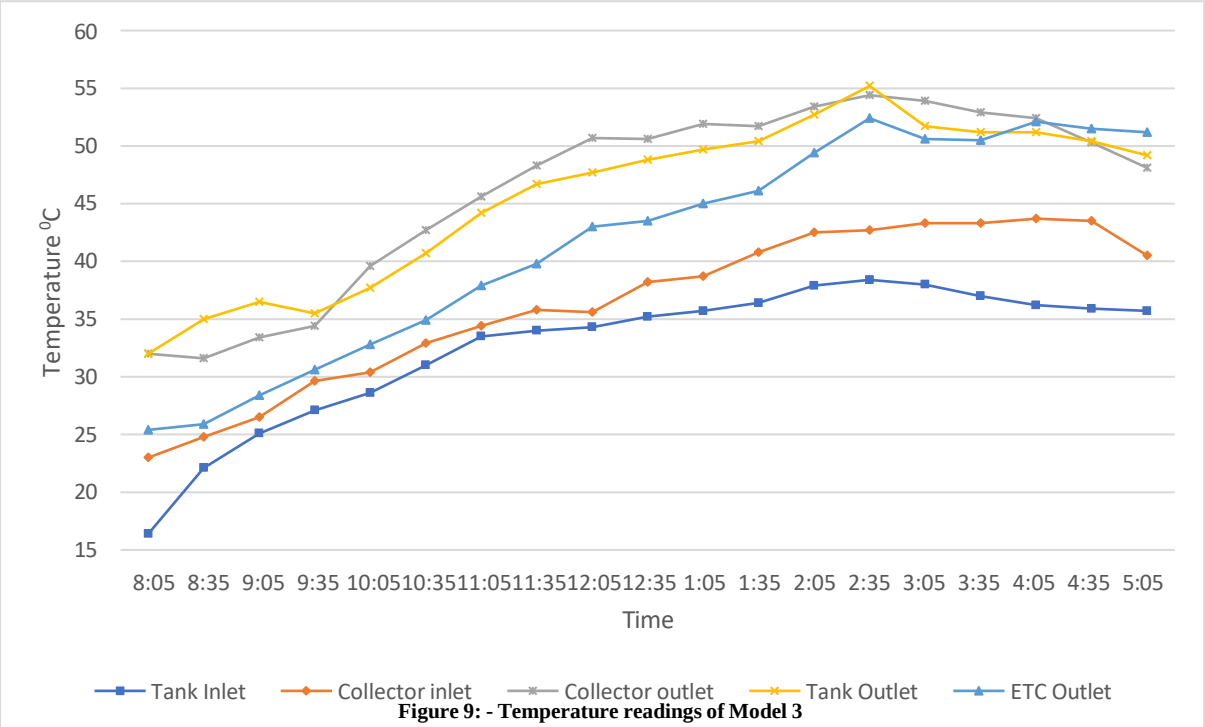

Figure 9: - Temperature readings of Model 3

4.1. Model 3

Figure 9 shows the performance of model 3 where the collector is constructed with the 40mm diameter pipes are eccentrically fixed in 50mm diameter pipes. The readings were taken from 8:00 AM till 5.00PM with the initial temperature of 26°C at inlet with the final temperature of 52°C was reached. The dead volume in model 3 is 9.5 liters. Time required for the water to reach maximum temperature of 58°C is 5.5 hours this temperature is attained at 2:30 PM. It is observed that due to 9.5 liters of dead volume, compared with model 1 and model 2 it is in-between first two models, time required to have maximum temperature of water outlet from collector is also changed. As effective aperture utilization is increased, the time required to heat 100 liters of water is less compared to first two models.

5. Conclusion

Solar heat gain for water heating is considered similar to flat plate collector (FPC)and ETC. In model 1 with the 32mm pipes the dead volume is 13.26 liters, which is quite high and increases the time for thermosyphon, where as the model 2 has an eccentrically fixed 32mm pipes in 40mm pipes with reduced dead volume to 5.5 liters. This reduction in dead volume improves thermos-syphon circulation between collector and hot water tank. Increase in absorber pipe diameter, not only increases solar aperture utilization but also decreases the gap between the array of bottles which reduces the convection loss. With the 3rd model an eccentrically fixed 40 mm pipes in 50mm pipes optimizes the dead volume up to 9.5 liters. With 50mm diameter pipes the solar aperture area for the absorption of solar radiation increases which decreases the time required for heating of water of same capacity.

The waste to best solar water heater can be seen as a combination of ETC and flat plate solar collectors with improved performance with less production cost. Present work gives some of the advantages of flat plate collectors (FPC) and some of the ETC. In FPC forced circulation, draining of deposited salts is possible and for ETC no insulation is required for collector.

Due to optimized cost of collector this type of collector will provide techno commercially viable solution.

6. References

[1] P. Denholm. The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States, Technical Report NREL/TP-640-41157 March 2007

[2] US Environmental Protection Agency. (2000). Health Effects of Breathing Woodsmoke. Retrieved July 26, 2014, from http://www.epa.gov/burnwise/pdfs/woodsmoke_health_effects_jan07.pdf

[3] Jorge de la Torre. Feasibility overview of a solar water heater made of polyethylene terephthalate bottles for rural areas in Guatemala. Institute of Science and Technology for Development, Rafael Landivar University

[4] Amal. H . Husain. Solar Water Heater From plastic Bottles and Beverage carton. Journal of Engineering and Development, Vol. 16, No.2, June 2012 ISSN 1813- 7822

[5] Javeriya Siddiqui and Govind Pandey. A Review of Plastic Waste Management Strategies. International Research Journal of Environment Sciences ISSN 2319–1414 Vol. 2(12), 84-88, December (2013)

[6] Indian patent applied, Sanjeev D Suryawanshi et.al. “Solar collector using plastic glazing”, Patent number Patent number 455451, dated 27/09/2023

[7] Solar water heater evacuated tube import data, https://www.seair.co.in/solar-water-heater-evacuated-tube-import-data.aspx